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A proposed maximum power point operating strategy for photovoltaic applications using monthly irradiance estimates

Prashant Upadhyay [a,*], Subrahmanyam Pulipaka [a], Madhav Sharma [b], Rajneesh Kumar [a]

[a] Department of Electrical and Electronics Engineering, Birla Institute of Technology and Science, Pilani, India
[b] Electrical Engineering Department, College of Technology, G. B. Pant University of Agriculture and Technology, Pantnagar, India

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ABSTRACT

In this paper, we propose a new application of irradiance estimate for photovoltaic (PV) applications. Maximum power point (MPP) operating strategy for PV system is developed using monthly irradiance estimate based duty cycle control. Duty cycle of DC-DC converter is calculated using monthly average irradiance (G_{av}) and average of maximum irradiance ($G_{max,av}$) received at Pilani during 2002–2011. Designed PV system operates at 60–95% of MPP throughout the year with these monthly irradiances based duty cycle operations. MPP of 71.6% and 66.81% is observed for January and July months respectively when the model is validated for weighted mean of maximum power point (w_{MPP}) operation. Further, a % MPP of 98.21 is achieved when proposed strategy is tested at short interval irradiance estimate based duty cycle control. Extensive simulation using MATLAB/SIMULINK is carried out to observe the operating points of PV system under dynamic changing irradiances levels. Experiments using solar array simulator (SAS) are performed to validate the simulated results.

1. Introduction

Integration of solar PV systems in renewable energy production is increasing rapidly across the globe Markets (2015). To ensure efficient utilization of these systems throughout the year, various maximum power point operation strategies are proposed in literature. Enslin (1992) and Enslin et al. (1997) observed 15–25% increase in efficiency and a cost saving of 10–15% when PV systems operate at MPP. Tey and Mekhilef (2014) developed a MPPT algorithm which is sensitive to irradiance changes due to cloud, rain and fog. Similarly, Zhao et al. (2015) proposed a novel way to overcome the dynamic and impulsive changes of daily irradiance effect on MPP operation. Bayod-Rújula and Cebollero-Abián (2014) proposed a MPP tracking technique with photo-diodes as a sensor to stabilize fluctuation due to irradiance changes. Further, MPPT algorithm based on uniform and non-uniform Irradiances is discussed by Logeswaran and SenthilKumar (2014). Apart from natural variation in irradiance, partial shading also causes irradiance change which shifts MPP of PV systems. Qi et al. (2014), Muthuramalingam and Manoharan (2014) and Boukenoui et al. (2016) developed MPPT techniques with multiple peak characteristics behavior, based on global as well as local maximum power points to negate the effect of partial shading. Similarly, Radjai et al. (2014) developed a fuzzy based duty cycle change estimator for accurate MPP operation under dynamic environmental conditions. Li (2014) proposed a new converter topology for accurate MPPT under varying weather conditions without using DC-DC converter.

These MPPT techniques are based on output voltage and current sensing to achieve maximum power point operation of PV systems. In this research work, a monthly irradiance estimate based MPP operation of PV system is proposed which eliminates the necessity of output voltage and current sensing. Monthly average irradiance (G_{av}) and monthly average of maximum irradiance ($G_{max,av}$) of test location are calculated using ten years irradiance data from 2002 to 2011. Operating point of PV system is controlled using estimated value of duty cycle at these two irradiances for DC-DC converter. Proposed strategy is also tested for short interval irradiance estimates (daily, 7 h, 5 h, and 3 h), and results are analyzed to observe deviation in MPP from ideal condition. Proposed method also reduces the complexity of control circuitry used for MPP operation and eliminates the effects of sensor based malfunctioning under dynamically changing irradiance conditions. Additionally, in dynamic environment conditions this sensor free mechanism, as proved by Wolfs and Quan (2006) yields less operating losses with accurate MPP operation.

* Corresponding author at: Department of Electrical and Electronics Engineering, Vidyavihar, BITS Pilani, Pilani Campus, Rajasthan 333031, India.
E-mail address: prashantu42@gmail.com (P. Upadhyay).

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Nomenclature

MPP	maximum power point	V_{MP}	maximum power voltage
PV	photovoltaic	I_{MP}	maximum power current
T	temperature	R_s	series resistance
T_{min}	minimum temperature	R_{sh}	shunt resistance
T_{max}	maximum temperature	T_{av}	average temperature
G	irradiance	G_{STC}	irradiance at standard test condition
I_{ph}	photo current	G_{av}	monthly average irradiance
I_{sc}	short circuit current	$G_{max,av}$	average maximum irradiance
$I_{SC\text{-}STC}$	short circuit current at standard test condition	$I_{MP,STC}$	maximum power current at standard test condition
$V_{OC\text{-}STC}$	open circuit voltage at standard test condition	$V_{MP,STC}$	maximum power voltage at standard test condition
W_{MPP}	weighted mean of maximum power point	T_{STC}	temperature at standard test condition
V_{oc}	open circuit voltage	V_{OP}	operating point voltage
K_1	temperature coefficient of current (A/°C)	I_{OP}	operating point current
K_2	temperature coefficient of voltage (V/°C)	P_{OP}	operating point power
a	diode identity factor		

2. Average irradiance and average maximum irradiance

2.1. Average irradiance

Accurate estimate and forecast of irradiance is necessary for PV plant installation at a given location. It determines the power output of these plants in real time as well as at later stages of operation. There are many techniques reported in the literature to estimate and forecast irradiance of a given location. For example, neural network models were developed by Mazorra Aguiar et al. (2015) with satellite data as inputs, Paoli et al. (2010) used daily solar radiation data and Wang et al. (2012) utilized statistical feature of solar radiation data as input to neural network model. Kaushika et al. (2014) used all three solar radiation data for neural network modeling while spatial averaging of the sensed data is analyzed by Lorenzo et al. (2015) to forecast irradiance. Mathematical models are also available to predict monthly, daily and hourly irradiances. Aryaputera et al. (2015), McCandless et al. (2015), Chu et al. (2015), Ahmad et al. (2015), Behrang et al. (2010) and Torregrossa et al. (2016) are recent examples of such contributions. Research carried out by Ghayekhloo et al. (2015) and Gastón-Romeo et al. (2011) used clustering to model and forecast irradiance.

This research work is carried out at Pilani, located in the north east part of Rajasthan, India at latitude 28.37°N and longitude 75.6°E as shown in Fig. 1. It receives high solar radiation throughout the year with 325 sunny days and direct normal insolation ranging from 1800 kW h/m^2 to 2600 kW h/m^2.

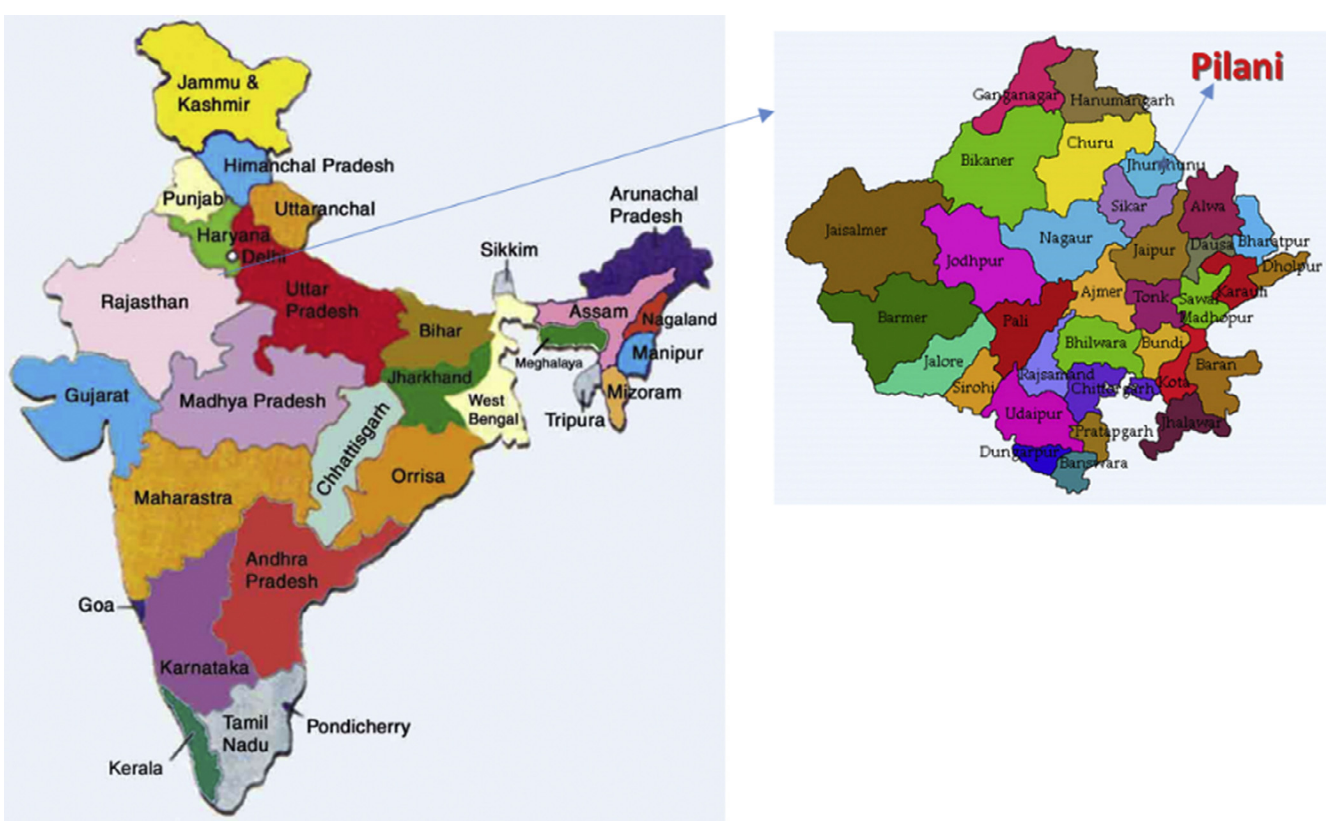

Fig. 1. Location of Pilani.